METHOD AND APPARATUS FOR PROVIDING
NON 2:1 GILBERT CELL MIXER

FIELD OF THE INVENTION

[0001]   This invention relates in general to mixer circuits, and more particularly to Gilbert cell mixers and related methods.

BACKGROUND

[0002]   In recent years there has been notable progress and changes in the world of telecommunications. In particular, the development of new integrated electronic devices on semiconductors has contributed to a large number of these changes. Amongst these improvements is the reduction of power consumption in portable electronic equipment. This reduction of energy consumption has permitted a reduction in weight and dimensions of this portable equipment, lengthening at the same time their useful life. All this has resulted in a large decrease in costs, something that has made this type of portable electronic equipment accessible to a large part of the population as for example mobile cellular telephones or portable computers. The effort to reduce the size of electronic circuitry is continuing.

[0003]   This growing demand for low voltage, low power, low cost and high performance mobile communications equipment has changed the way wireless receivers are designed. A fundamental building block for radio frequency transceivers in such electronic circuitry is a modulator/demodulator. Modulators are used to modulate a data input such as a voice input, onto a carrier frequency. Modulators are also referred to as "mixers" or "multipliers". Demodulators are used to demodulate data from a high frequency carrier. For example, in a mobile telephone, a modulator/demodulator is used for the telephone transceiver.

[0004]   Mixers may be broadly classified as either passive

or active. Passive mixers, for example, may be based upon a FET or diode ring and provide no conversion gain. However, the active mixer approach yields lower conversion loss and/or gain, and a good degree of balance. A particular type of active modulator that is widely used is the "Gilbert Multiplier Cell", also referred to as the "Gilbert Modulator", the "Gilbert Cell" or the "Gilbert Mixer".

[0005]   The Gilbert Multiplier Cell includes a source-coupled transistor pair, also referred to as the lower transistors or driver transistors, which is coupled to a pair of cross-coupled source-coupled transistor pairs, also referred to as the upper transistors, switch transistors or active mixer transistors. For example, RF inputs may be coupled to the source-coupled transistor pair and a local oscillator is coupled to the pair of cross-coupled source-coupled transistor pairs to produce a demodulated output. The Gilbert Multiplier Cell is extensively described and analyzed in Section 10.3 of the textbook "Analysis and Design of Analog Integrated Circuits" by Paul Gray and Robert Meyer, John Wiley and Sons, N.Y., 1993, pp. 670-675.

[0006]   Prior mixer topologies exhibit disadvantages as the supply voltage is decreased. In a Gilbert cell mixer, the minimum supply voltage is defined by three transistors connected across the supply voltage as well as series connected the load resistances. The required voltage drop over transistors is technology dependent. Attempts to reduce the supply voltage may result in transistors of the differential or long tailed pairs going into the linear region, which has a number of disadvantageous effects. Also, large current through the switching transistors necessitates a large LO drive to provide the desired IR drop through the switching transistors. Further, higher third-order intercept points are needed to amplify large signals without distortion. However, as technologies shrink so do the supply voltages thereby demanding mixer designs that can operate at lower supply voltages while providing the needed performance.

[0007]   It can be seen then that there is a need for a

mixer that provides lower voltage operation, lower LO drive
and better linearity.

SUMMARY

[0008]   To overcome the limitations in the prior art
described above, and to overcome other limitations that will
become apparent upon reading and understanding the present
specification, the present invention discloses a Gilbert cell
mixer and related methods.

[0009]   The present invention solves the above-described
problems by providing a mixer that provides lower voltage
operation, lower LO drive and better linearity. Additional
current sources are provided to drive the lower, source-
coupled transistor pair thereby allowing operation of the
switch transistors with lower current.

[0010]   A mixer in accordance with the principles of the
present invention includes a differential amplifier for
receiving and amplifying input signals, the amplifier stage
providing a predetermined gain to the input signals, a load
for providing a load impedance, a dual differential switching
stage, coupled to the differential amplifier and the load, the
dual differential switching stage mixing the amplified input
signals from the differential amplifier with a local
oscillator signal to produce an output signal at the load and
a current modifier, coupled to the differential amplifier, the
current modifier altering current in the differential
amplifier to adjust current through the load.

[0011]   In another embodiment of the present invention,
another mixer is provided. This mixer includes a Gilbert cell
comprising an RF amplifier stage and a mixer stage and a
current modifier, coupled to the differential amplifier, the
current modifier altering current in the differential
amplifier to adjust current through the load.

[0012]   In another embodiment of the present invention, a
method for mixing two signals is provided. The method
includes providing a Gilbert cell comprising an RF amplifier

stage and a mixer stage and injecting current into the amplifier stage to reduce current through the mixer stage by supplementing current in the amplifier stage.

[0013]   In another embodiment of the present invention, a method for mixing two signals is provided. This method includes providing a Gilbert cell comprising an RF amplifier stage and a mixer stage and sinking current from the amplifier stage to alter current through the mixer stage.

[0014]   In another embodiment of the present invention, another mixer is provided. This mixer includes means for amplifying an input signal, means for receiving the amplified input signal and for providing a balanced differential output signal having a first frequency translated using the frequency of the amplified input signal and means, coupled to the means for amplifying, for injecting current into the means for amplifying to reduce current through the means for receiving the amplified input signal and for providing a balanced differential output signal by supplementing current in the means for amplifying.

[0015]   In another embodiment of the present invention, another mixer is provided. This mixer includes means for amplifying an input signal, means for receiving the amplified input signal and for providing a balanced differential output signal having a first frequency translated using the frequency of the amplified input signal and means, coupled to the means for amplifying, for sinking current from the means for amplifying to alter current through the means for receiving the amplified input signal and for providing a balanced differential output signal.

[0016]   These and various other advantages and features of novelty which characterize the invention are pointed out with particularity in the claims annexed hereto and form a part hereof. However, for a better understanding of the invention, its advantages, and the objects obtained by its use, reference should be made to the drawings which form a further part hereof, and to accompanying descriptive matter, in which there

are illustrated and described specific examples of an apparatus in accordance with the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017]   Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

[0018]   Fig. 1 illustrates a block diagram of a Gilbert cell mixer;

[0019]   Fig. 2 illustrates a first Gilbert cell mixer topology

[0020]   Fig. 3 illustrates a second Gilbert cell mixer topology;

[0021]   Fig. 4 illustrates a third Gilbert cell mixer topology;

[0022]   Fig. 5 illustrates a non 2:1 Gilbert cell mixer according to an embodiment of the present invention; and

[0023]   Fig. 6 is a block diagram of a Gilbert cell mixer according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0024]   In the following description of the embodiments, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration the specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized because structural changes may be made without departing from the scope of the present invention.

[0025]   The present invention provides a Gilbert cell mixer and related methods. A Gilbert cell mixer according to the present invention may be implemented as a demodulator and provides lower voltage operation, lower LO drive and better linearity. The Gilbert cell mixer includes additional current sources to drive the lower, source-coupled transistor pair thereby allowing operation of the switch transistors with lower current.

[0026]   Fig. 1 illustrates a block diagram of a Gilbert

cell mixer 100. The Gilbert cell mixer includes an RF input
signal 101 is fed to a RF input transconductor amplifier 103
such as a differential pair. The RF signal is amplified and
then input to a mixer 105 formed by a plurality of switching
devices. The mixer 105 works to provide sum and difference
RF signals based on the frequency of the input signals from
RF input transconductor amplifier 103 and the local
oscillator (LO) input signals 107. With proper application
of a differential load 109 and the voltage supply 111, the
resultant output signals are provided at the output 113.

[0027]   Figs. 2-4 illustrate three prior mixer circuit
topologies. However, as technologies shrink so do the supply
voltages. All three of the mixer topologies shown in Figs.
2-4 have disadvantages as the supply voltage is decreased.

[0028]   Fig. 2 illustrates a first Gilbert cell mixer
topology 200. The Gilbert cell mixer includes an RF input
transconductor amplifier 203, core switching devices 205 and
differential load 209. The Gilbert cell mixer topology 200
has highly negative aspects because the AC gain and IR drop
are a function of the load resister. A Gilbert cell mixer
topology 200 implemented with bipolar junction transistors
(BJT) is described in detail in "DESIGN CONSIDERATIONS FOR
BJT ACTIVE MIXERS", by Barrie Gilbert, Workshop Notes, Analog
Devices, Inc., Rev. 2.2, Sep. 4, 1994. However, those
skilled in the art will recognize that the Gilbert cell
mixers may be implemented using other embodiments than BJT
Gilbert cell mixers, including MOS embodiments.

[0029]   Gilbert cell mixers include four transistors 210,
211, 220, 221, known as an upper quad core of transistors
205. The upper quad core of transistors 205 are
differentially connected in a common source configuration and
in turn connected to a differentially connected at the lower,
source coupled driver transistors 201, 202. As shown in FIG.
2, the Gilbert cell mixer 200 has two input ports RF+ 260,
RF- 262, and output ports 270, 272.

[0030]   A first pair of NMOS transistors 201, 202 has a

common source terminal 204 that is connected to the drain of transistor 208. The source of transistor 208 is connected to the negative supply rail 207. The gate of transistor 208 controls the tail current through transistor 208. The drain of the first NMOS transistor 201 is connected to the common sources of a second NMOS pair 210, 211 and the drain of the second NMOS transistor 202 is connected to the common sources of a third NMOS pair 220, 221. The gates of the transistors 211 and 221 are connected together 226. The drain of transistor 210 is connected to the drain of transistor 221 at a node 222. The drains of the transistors 211 and 220 are connected together at a second node 223. The first node 222 is connected to a first output resistor 230, which is connected to the supply rail 240. The second node 223 is connected to a second output resistor 232, which is connected to the positive supply rail via 240.

[0031]   Fig. 3 illustrates a second Gilbert cell mixer topology 300. The Gilbert cell mixer topology 300 improves upon the design 200 shown in Fig. 2 by decoupling the IR drop and the AC gain. The resistors control the AC gain, while the IR drop is controlled by the PMOS transistor's V_t, W/L, I_d. To maintain a small IR drop, W and L are usually large thereby resulting in a large capacitance. This large capacitance limits the frequency response and effectively the maximum resistance allowed because the capacitance tends to dominate after a few kilo-ohms (k∘) of resistance.

[0032]   Fig. 4 illustrates a third Gilbert cell mixer topology 400. The Gilbert cell mixer topology 300 improves upon the topologies 200, 300 of Figs. 2-3 by placing the PMOS load transistors in a servo loop. The input transconductance stage consists of a simple differential pair 401, 404. The cascode devices 402, 403 provide LO-to-RF isolation. Devices 410, 411, 420, 421 act as switches in the mixer. Devices 406, 407 are used to set both the load and the gain that may be modulated on-chip by varying the current through diode-connected device 409. Common-mode feedback is achieved with devices 412, 414, 416, and the current source consisting of

devices 418, 419. Devices 416, 418, 419 are connected to the
supply rail 440. Compensation for the common-mode feedback
loop is provided with capacitor 424. The Gilbert cell mixer
400 has two input ports $V_{in}+$ 460, $V_{in}-$ 462, and two output
ports 470, 472. Devices 401, 404 have a common source
terminal 405 that is connected to current source 408, which
in turn is connected to the negative supply rail, V_{ss}, 407.
By placing the PMOS load transistors in a servo loop, the IR
drop across the PMOS load can be as low as a Δv, i.e.,

$\sqrt{2I_d / B}$. However, this is achieved by using a more complex

circuit, more current and more biases.

[0033]   Fig. 5 illustrates a non 2:1 Gilbert cell mixer 500
according to an embodiment of the present invention. As
illustrated above, in a typical Gilbert cell mixer, the
current through each of the input amplifier transistors is
twice the current through the transistors of the switching
devices, and the current through the current source
transistor is twice each of the input amplifier transistors,
i.e., a 2:1 Gilbert cell mixer. However, the Gilbert cell
mixer 500 according to an embodiment of the present invention
includes current sources 580, 582 that free the circuit 500
from the 2:1 requirement.

[0034]   The Gilbert cell mixer 500 according to an
embodiment of the present invention includes four transistors
510, 511, 520, 521, known as an upper quad core of
transistors 505. The upper quad core of transistors 505 are
differentially connected in a common source configuration and
in turn connected to a differentially connected at the lower,
source coupled driver transistors 501, 502. As shown in FIG.
5, the Gilbert cell mixer 500 has two input ports RF+ 560,
RF- 562, and output ports 570, 572.

[0035]   A first pair of NMOS transistors 501, 502 has a
common source terminal 504 that is connected to the drain of
transistor 508. The source of transistor 508 is connected to
the negative supply rail 507. The gate of transistor 508
controls the tail current through transistor 508. The drain

of the first NMOS transistor 501 is connected to the common
sources of a second NMOS pair 510, 511 and the drain of the
second NMOS transistor 502 is connected to the common sources
of a third NMOS pair 520, 521. The gates of the transistors
511 and 521 are connected together 526. The drain of
transistor 510 is connected to the drain of transistor 521 at
a node 522. The drains of the transistors 511 and 520 are
connected together at a second node 523. The first node 522
is connected to a first output resistor 530, which is
connected to the supply rail 540. The second node 523 is
connected to a second output resistor 532, which is connected
to the positive supply rail via 540.

[0036] The Gilbert cell mixer 500 of Fig. 5 also includes
two additional current sources 580, 582 that allow the
current through the upper quad transistors 510, 511, 520, 521
to be reduced and therefore operate at much lower supply
voltages. The current sources 580, 582 provide additional
current to the lower, source-coupled transistors 501, 502.
The current sources 580, 582 thus provide lower voltage
operation, lower LO drive and better linearity. The current
sources are shown providing current to the circuit as well as
including the arrows reversed to indicated that the current
sources may be current sinks for sinking current away to
alter the current requirements through the core switching
devices 505 and RF input transconductor amplifier 503.

[0037] The Gilbert cell mixer of Fig. 5 allows less
current to flow into the load, which reduces the IR drop in
the load thereby allowing for lower supply voltages. Even if
headroom isn't a problem, reducing the current through the
switching transistors 510, 511, 520, 521 allows a reduction
in the LO drive to give the same IR drop through the
switching transistors 510, 511, 520, 521. By using less
current through the LO switching transistors 510, 511, 520,
521 the IR drop across these transistors 510, 511, 520, 521
gets lower (for a given V_{gs}) but if headroom isn't an issue
one can increase the resistance of the switching transistors
510, 511, 520, 521 back to the original value by reducing the

gate to source voltage(V_{gs}). The gate to source voltage is directly related to LO drive. Hence by reducing the V_{gs} on the switching transistors 510, 511, 520, 521, the LO drive may also be lowered.

[0038]   An additional advantage of The Gilbert cell mixer of Fig. 5 if headroom isn't a major issue is that the biasing may be modified to provide better linearity. Better linearity leads to less distortion and therefore better third order intercept point (IP3) numbers. Increasing V_{ds} of the RF transistors 501, 502 moves the signal swing to a more linear portion of the transistors IV curve. This produces lower non-linearity and hence better third order intercept point (IP3). The higher the intercept point, the better the device can amplify large signals without distortion. Although mixers are based on a fundamental non-linear principle, it is important that the mixer must also be able to amplify a range of incoming signals in a linear fashion.

[0039]   For example, consider the scenario of having two input signals spaced relatively close together on the frequency spectrum fed into the mixer, one being the desired signal in the channel of interest and the other being the undesired signal (an interfering signal of the adjacent channel). The collaborated effects of these signals are known as inter-modulation. Most critical are third-order inter-modulation (IM3) components that appear at the output of the mixer. Their frequencies of $2\omega_{RF+} - \omega_{RF-}$ and $2\omega_{RF-} - \omega_{RF+}$ may lie within the passband of the desired IF, subsequent to the mixing operation. As the RF input power increases, the output power of the undesired IM3 signals will intersect the output power of the desired signal. It is this intersection that is referred to as the IP3 point.

[0040]   Fig. 6 is a block diagram of a Gilbert cell mixer according to an embodiment of the present invention. The Gilbert cell mixer includes an RF input transconductor amplifier 603, core switching devices 605 and differential load 609. The Gilbert cell mixer 600 of Fig. 6 also includes

two additional current sources 680, 682 that allow the current through the core switching devices 605 to be reduced and therefore operate at much lower supply voltages. The current sources 680, 682 provide additional current to the RF input transconductor amplifier 603. The current sources 680, 682 thus provide lower voltage operation, lower LO drive and better linearity.

[0041]   Figs. 5-6 show a current source being provided for altering the current requirements through the core switching devices 505, 605 and RF input transconductor amplifier 503, 603. However, the current modifier could be a current sink for sinking current away to alter the current requirements through the core switching devices 505, 605 and RF input transconductor amplifier 503, 603. Moreover, while the invention has been described in the drawings referenced above using FET transistors, the present invention is not meant to be limited to a particular transistor device. Rather, the principles for providing a non 2:1 Gilbert cell mixer according to the embodiments of the present invention are applicable to different semiconductor technologies.

[0042]   The foregoing description of the exemplary embodiment of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not with this detailed description, but rather by the claims appended hereto.